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FIBER LASER AMPLIFIERS AND OSCILLATORS

KJT Inc.

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13. ABSTRACT (Maximum 200 words)
A tunable erbium doped fiber ring laser, pumped with a 980 nm diode laser was constructed. Output power as a function of pump power and output wavelength for a given fiber length was measured. Spectral and temporal analysis of the signal showed mode-locked pulses of short duration and broad frequency content, as well as a CW component confined to a relatively narrow optical frequency range. The mechanisms for this type of mode-locking are discussed as well as the limitations placed on the lasing line width and spectral tunability.

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A Simple Mode Locked Erbium Fiber Laser

KJT Inc.

I. Introduction

Various types of mode locked fiber laser oscillators designed to produce short pulses at wavelengths in the 1.55 micron telecommunications window have been developed recently. Such oscillators are attractive sources of optical solitons and therefore important in advanced high speed optical communications systems. Most mode locked fiber oscillators have been constructed so as to minimize pulse width through the use of specially designed amplifiers and auxillary components. These oscillators usually required high pump powers and very often were not self starting. The objective of the present work was the construction and characterization of a laser oscillator based on a commercial erbium doped fiber amplifier designed to produce high gain over as wide a spectral range near 1.55 microns with a minimum amount of pump power. From a practical standpoint it is natural to ask whether or not such well engineered and efficient amplifiers can be readily converted to laser oscillators operating in either the CW or pulsed mode. Preliminary results on such a system were reported earlier.[1] In this report we describe a simple self starting diode pumped mode locked laser oscillator which involves a minimum number of readily available parts.

II. Experimental

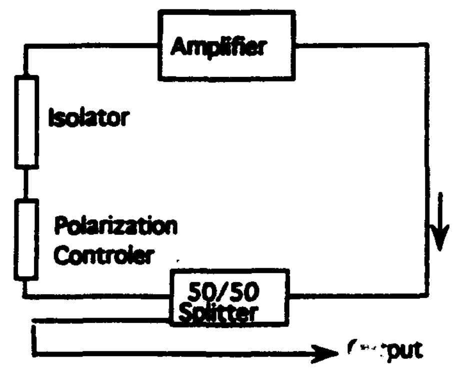

Fig. 1 Oscillator La

The layout of the oscillator is shown in Fig. 1. An unmodified erbium doped fiber amplifier manufactured by Corning, Incorporated (FiberGain Module model P3-35) was used in a unidirectional ring laser configuration. The output of the amplifier was connected to its input through a 50/50 all fiber splitter, a polarization controller, and a non- polarizing pigtailed isolator. These components were fusion spliced together to reduce etalon effects which are known to reduce the bandwidth available for mode locking.[2]

III. Results

The time averaged output of the oscillator was measured as a function of launched pump power using a standard power meter. The launched pump power at the threshold for oscillation was found to be about 4 mW, while the output power was 3 mW for a pump power of 25 mW.

The optical spectrum and the temporal behavior of the oscillator output were also examined as a function of pump power. It was found that at threshold and above; the output always consisted of a CW component and a train of short pulses. The short pulse component of the output was completely self starting. Fig. 2 illustrates this behavior. Here the output from a detector with a response time of about 100 ps displayed on an oscilloscope having a band pass of 10 GHz is shown.

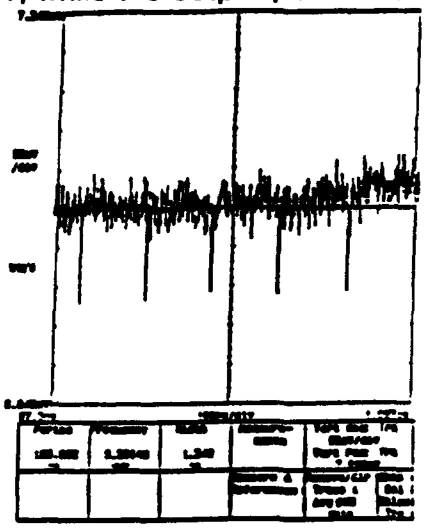

Fig. 2. Oscillator output at 8 mW pump power.

The period of the pulse train was remarkably stable and independent of pump power, so that the signal could be averaged to accurately measure the pulse period and average width. In the case shown in figure 2, the average pulse width was 1.3 ns, while the period was 186 ns. The contrast between the height of the pulses and the noise due to CW oscillation could be maximized by a carefull adjustment of the polarization controller. It was also found that this contrast was best at low pump powers, near the threshold for oscillation. As the pump power was increased, noise due to CW oscillation and sporadic harmonic signals apparently caused by mode beating also increased relative to the periodic structure. The period of the output pulses was measured as a function of the length of the oscillator cavity. This data was obtained by fusion splicing known lengths of standard telecommunications fiber into the feed back loop. It was found that the pulse period was strictly proportional to the cavity length. The total optical length of the oscillator cavity was calculated from measured values of the period and ranged from 40 to 50 M.

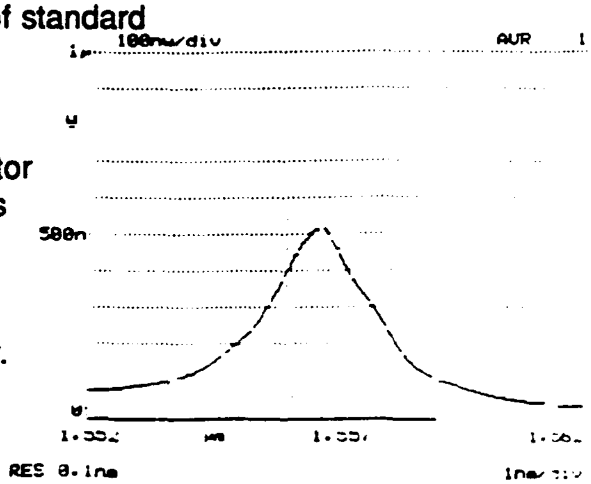

Fig. 3 Optical spectrum near threshold.

The optical spectrum of the oscillator was also measured as a function of pump power. Near threshold the spectrum consisted of a band with a full width at half maximum of about 2 nm centered at 1.56 nm. This is illustrated in figure 3. As the pump power was increased, oscillation occured in several narrower bands as is illustrated in Fig. 4. The central band shown here had a half width of about 0.5 nm.

The temporal behavior of the oscillator output was also analyzed with an autocorrelator. The result is shown in Fig. 5 for the same pump power used to obtain the data presented in Fig. 4. The presence of temporal pulses with a full width at half maximum of about 35 ps. is indicated by this data. At pump powers which yielded the spectral data shown in Fig. 5, the output power of the oscillator was too low for autocorrelation measurements to be made.

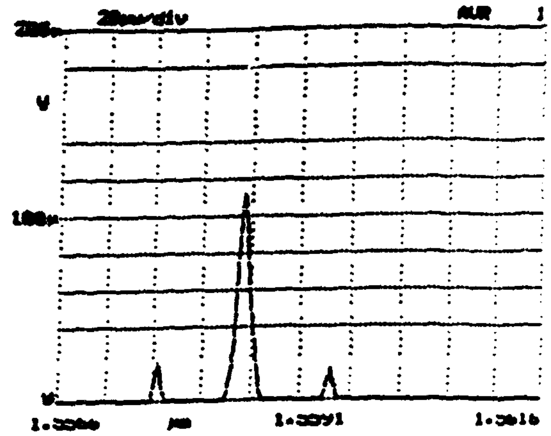

Fig. 4. Spectrum at 20 mW pump power.

IV. Discussion and Conclusions

The appearance of a stable train of short pulses with a period set by the length of the oscillator cavity indicates that some form of self mode locking was occuring in the laser oscillator described above. The presence of structure on a picosecond scale in addition to the relatively broader nanosecond scale pulses is further evidence of mode locking. A comparison of Figs. 6 and 7 indicates that this picosecond structure was band width limited. It is possible that the observed nanosecond pulses contained trains of picosecond pulses which were not resolved by the photodetection system used to obtain the data shown in Fig. 2. This behavior has been observed in other types of erbium doped fiber oscillators.[3] The broad spectral band observed near threshold (Fig. 3) indicates the possibilty of bandwidth limited structure as narrow as 2 ps. It is worth noting that the self mode locking of this oscillator was completely self starting. In fact, mode locking seemed to be the preferred method of oscillation and persisted over the entire range of pump powers investigated. It should also be noted that the pump powers used in this investigation were relativly low compared to those reported in other work.

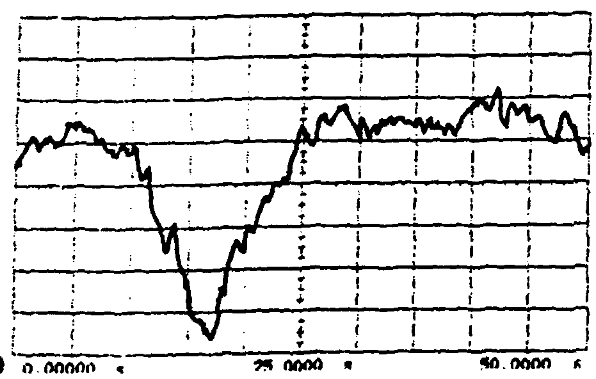

Fig. 5. Autocorrelation trace of output at 20 mW pump power. One major division equals 25 ps.

It is interesting to speculate on the mechanism responsible for mode locking in the simple system used in this work. In the first place it should be noted that the very long cavity employed here results in a very dense temporal mode structure. For example, a period of 186 ns corresponds to a temporal mode separation of 8.33 MHz. The narrowest optical spectrum observed in this work covered a spectral range of 0.15 nm, which corresponds to a frequency width of 11.5 GHz. This range of frequencies overlaps approximately 1.4×10^3 longitudinal modes! The band width limited spectral range required for 1.3 ns wide pulses is about 10^{-2} nm or 1.77 GHz. Even this narrow spectral range includes about 200 longitudinal modes. In other words, the small temporal mode separation due to a long cavity permits mode locking to occur over a very small fraction of the available gain curve of the fiber amplifier, reducing the effect of dispersion on mode separation. This makes a large number of modes with equal separations available for mode locking, and may explain why mode locking occured so easily in this oscillator.

There appear to be two classes of mode interactions available in the simple cavity used in this work.These are non linear effects in the external feedback loop,such as self phase modulation or non linear polarization rotation[4,5], or non linear effects which modulate the gain medium itself.[6] It should be noted, however, that the peak powers occuring in the observed mode locked pulses are relatively low, especially near the threshold for oscillation where the most stable operation is observed. For example, for an average power of 1.0 mW, the peak power in one of the mode locked pulses of 35 ps duration was approximately 5.3 W, assuming that no CW oscillation was occurring. For this peak power it can be shown that the fiber length required for non linear effects is about 112 m.[7] Since the maximum length of the cavity used here was 50 m, and the estimate of the peak power made above is undoubtedly too high, non linear effects in the external cavity can be neglected. It is more likely that non linear effects in the gain medium itself, such as spatial or temporal saturation effects, provide the interaction which locks the temporal modes.

In summary, we have observed completely self starting mode locked behavior at very low pump powers in an oscillator utilizing a simple ring cavity and a commercial diode pumped erbium doped fiber amplifier package.

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